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Bioconstructions in the Mediterranean: Present and Future

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Abstract

In the Mediterranean Sea, most important habitat formers are bioconstructors. Bioconstructors provide habitats for a large variety of organisms and these organisms rely on bioconstructors as a source of food and shelter. Marine bioconstructors in temperate seas have been recognized to have a structural and functional role of marine biodiversity (as a habitat formers and ecosystem engineers), the same as coral reefs in tropical regions. Bioconstructors are ranging from coralligenous formations (formed usually by coralline algae, sponges, cnidarians, and bryozoans) to vermetid reefs, deep-sea white corals and oyster banks. Some habitats like coral banks formed by shallow-water coral *Cladocora caespitosa* od deep-water coral *Lophelia pertusa*, together with coralligenous buildups and maerl beds are of special interest for scientists and people involving with nature protection. Habitat degradation, destruction, fragmentation and loss are the most dramatic consequences of anthropogenic pressures on natural ecosystems and marine bioconstructors as a part of that. Under the present climate warming trend, together with marine acidification, new mass mortality events may occur in the near future, possibly driving a major biodiversity crisis in the Mediterranean Sea, especially in Mediterranean bioconstructors.

Keywords:

Anthropogenic pressures • Bioconstructors • Biodiversity crisis • *Cladocora caespitosa* • Climate warming trend • Coralligenous buildups • Coralligenous formations • Deep-sea white corals • Ecosystem engineers • Habitat formers • *Lophelia pertusa* • Maerl beds • Marine acidification • Mass mortality events • Mediterranean bioconstructors • Mediterranean Sea • Temperate seas • Vermetid reefs

Bioconstructors and Mediterranean Biodiversity

Diversity Pattern

Marine bioconstructors are, in simplified sense, marine calcifying organisms, both pelagic and benthic. The term applies to organisms with hard skeletons that remain in place after death, becoming a secondary substrate for other organisms of the same species or non-bioconstructors. They are best represented by tropical coral reefs, but are also present in temperate seas. Their impact in temperate seas is often neglected, and knowledge of the carbonate production of

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Fig. 25.1 The *Cladocora caespitosa* bank in the Mljet National Park (Southern Adriatic Sea)

non-tropical species is scarce. In the Mediterranean Sea, most important habitat formers are bioconstructors and they should have an adequate consideration in conservations policies (Bianchi and Morri 2000). Major carbonate marine frameworks are formed by long-living organisms such as encrusting red algae, corals, polychaetes, and bryozoans (Laborel 1987; Bianchi 1997, 2002; Bianchi and Morri 2004; Cocito and Ferdeghini 2001). Their growth is mainly temperature-dependent, and when abundant, these organisms may grow to a fairly large size. The largest biologically constructed features are coral reefs in tropical regions, although similar features (*Cladocora caespitosa* banks) are also known from the Mediterranean Sea during early Pleistocene (Peirano et al. 1998, 2004). Marine benthic bioconstructors have great significance in generating and maintaining marine biodiversity. A wide range of marine organisms acts as bioconstructors: coralline algae, sponges, corals (both symbiotic and non-symbiotic), vermetids, mussels, oysters, polychaetes (serpulids and sabellerids), barnacles and bryozoans. There is a great difference in bioconstructors diversity among tropical seas and temperate seas. Coral reefs in tropical seas are formed by large number of coral species, while in temperate seas, only a few species participate in bioconstructions. Similar examples could be found also in bryozoan species (Cocito 2004). Bryozoans and corals are known to form biohermal mounds in tropical, but also in temperate seas, like Mediterranean Sea. Bryozoan *Pentapora fascialis*, serpulid polychaete *Ficopomatus enigmaticus* and scleractinian coral *Cladocora caespitosa* are the most famous of all biconstructors in the Mediterranean Sea. The scleractinian coral *Cladocora caespitosa* belongs to the family Faviidae, a species known as important coral reef builders. Carbonate production of this coral can reach up to 10 kg $CaCO_3$ per m^2 $year^{-1}$, comparable to data from constructional, tropical corals (Peirano et al. 2001). The coral *C. caespitosa* deserves a special place in this group of Mediterranean bioconstructors. It is a bushy coral (dendroid form), with parallel growing calices. Living at depths of 4–30 m, this coral builds formations that are possibly related to the true coral reefs of tropical seas. *C. caespitosa* is an obligatorily zooxanthellate, characteristic of hermatypic tropical corals. It is an endemic Mediterranean coral and is found in beds of hemispherical colonies or in a form of coral bank produced by the fusion of adjacent colonies, covering several square meters (Morri et al. 1994; Peirano et al. 1998, 2001; Kružić and Požar-Domac 2003). Large banks of *C. caespitosa*, both living and fossil, have been found at several sites in the Mediterranean Sea: near the Tunisian coast and in the Aegean and Ligurian seas (Laborel 1961; Zibrowius 1980; Peirano et al. 1998). In the Adriatic Sea, Abel (1959) also described extensive colonies of *C. caespitosa* in the Lim channel near Rovinj, while Pax and Müller (1962) mention banks of *C. caespitosa* near the island of Mljet. The *C. caespitosa* bank in the Mljet National Park (Southern Croatia, the Adriatic Sea) ranges from depths of 6 to 18 m and covers an area of 650 m^2, forming one of the largest banks of *C. caespitosa* found in the Mediterranean Sea (Fig. 25.1). The strong currents, which occur as a result of tidal exchange in the channel, appear to favour the growth of the bank (Kružić 2002; Kružić and Požar-Domac 2003; Kružić and Benković 2008). These larger formations are very rare nowadays, compared to the Pleistocene when *C. caespitosa* formed true "reefs" during the warmer climatic stages (Bernasconi et al. 1997). The reason for this impoverishment is not known and could possibly be connected with climatic changes in the Mediterranean Sea and recent sea pollution. *C. caespitosa* tolerates relatively low winter temperatures in the Mediterranean Sea (as low as 6 °C measured in the northern Adriatic Sea) (Kružić and Benković 2008). Peirano et al. (2004) consider this coral a true biological recorder of recent and past climates. Recent studies of stable

Fig. 25.2 Coralligenous community in the Mljet National Park (Southern Adriatic Sea)

isotopes and trace elements in *C. caespitosa* have confirmed that this coral species can be used as an ideal candidate for reconstructing detailed climate and environmental changes (Montagna et al. 2007, 2008; Rodolfo-Metalpa et al. 2008). These authors provided evidence that this non-tropical coral represents a new, potentially important, high-resolution archive for climate variability in the Mediterranean Sea. Deep sea corals (most often stony corals) are also important for the Mediterranean biodiversity. Most of what we know about deep sea corals has come from exploration and research within the past few decades. With the development of underwater imaging technologies and complex vehicles like ROV (remotely operated vehicles), scientists have been able to begin the study of corals within their natural environment. Deep-water corals are widely distributed within the earth's oceans, with large reefs in the far North and far South Atlantic, as well as in the tropics in places such as the Florida coast. In the Mediterranean Sea, the principal coral species that contribute to reef formation are *Lophelia pertusa*, *Madrepora oculata, Desmophyllum dianthus*, *Dendrophyllia ramea* and *D. cornigera*. The last two are known as 'yellow corals' and live in the circalittoral zone, especially in the south-western areas of the Mediterranean, therefore showing a distribution typical of warm-water species (Bianchi 2007). *Madrepora oculata*, *Desmophyllum dianthus* and *Lophelia pertusa* are known as 'white corals', live in the bathyal zone and have a strong affinity for cold waters. Information on distribution of Mediterranean deep-water corals is still too scarce.

Coralligenous Community and Maërl Beds

Coralligenous buildups (hard bottom of biogenic origin always develop in almost vertical walls, deep channels, or overhangs) seem to be common all around the Mediterranean coasts, but one of the major gaps concerning the current state of knowledge of the coralligenous habitat is the absence of cartographical data. Coralligenous concretions are the result of the building activities of algal and animal builders and the physical as well as biological eroding processes (Ballesteros 2006). The final result is a very complex structure composed of several microhabitats (Fig. 25.2). Light is the most important environmental factor regarding the distribution of benthic organisms along the rocky bottoms of the continental shelf (Ballesteros 1992). Habitats situated in open waters (horizontal and vertical surfaces) can be easily distinguished from those situated in overhangs and cavities. Holes and cavities within the coralligenous structure always bear a complex community dominated by suspension feeders (anthozoans, bryozoans, serpulids and molluscs). Overhangs and big cavities of the coralligenous have a different species composition from that found in open waters. Algae are usually completely absent because light is very reduced.

Algae dominate in horizontal to sub-horizontal surfaces and their abundance decreases with depth and decreasing irradiance. Coralline algae are the main coralligenous builders (Laborel 1961). *Mesophyllum lichenoides* and *Mesophyllum* (*Pseudolithophyllum*) *expansum* has probably been identified by most authors as being the most common coralline algae in the coralligenous (Fig. 25.3).

Animal assemblages can greatly differ according to light levels reaching the coralligenous outcrop but also according to current intensity, sedimentation rates and geographical areas (Ballesteros 2006). In the richest, relatively more eutrophic zones, with rather constant and low water temperature, gorgonians usually dominate the community, but they are completely absent or rare in the more oligotrophic or low current areas with rather high or seasonally variable temperature, being replaced by poriferans, bryozoans or ascidians (Ballesteros 2006). Coralligenous animal builders are studied by Hong (1980) from the region of Marseilles. He found

Fig. 25.3 Coralline algae *Mesophyllum lichenoides* from the coralligenous community in the Mljet National Park (Southern Adriatic Sea)

a total number of 124 species contributing to the buildups. He found that the most abundant animal group are the bryozoans, accounting for 62 % of the species, followed by the serpulid polychaetes, with the 23.4 % of the species. Minor contributors are the cnidarians (4 %), molluscs (4 %), sponges (4 %), crustaceans (1.6 %) and foraminifers (0.8 %). Hong (1980) distinguished three different types of animal builders: (a) those directly contributing to the buildups, which are relatively big (bryozoans from the genus *Schizomavella*, *Celleporina*, *Myriapora*, serpulids *Serpula vermicularis* and *Serpula concharum*, the molluscs *Vermetus* sp. and *Thylacodes* (*Serpulorbis*) *arenarius*, and the scleractinian corals *Hoplangia durotrix*, *Leptopsammia pruvoti*, *Caryophyllia inornata* and *Caryophyllia smithii*); (b) those with a reduced buildup activity because of their small sizes (small bryozoans like *Crassimarginatella maderensis* and *Mollia patellaria*, serpulids like *Hydroides* spp., *Filogranula* spp., and *Spirorbis* spp., the cirripeds *Verruca strömia* and *Balanus perforatus*, and the foraminifer *Miniacina miniacea*) and (c) those which agglomerate carbonate particles (sponges like *Geodia* spp., *Spongia virgultosa* and *Faciospongia cavernosa*, bryozoans *Beania* spp. and the alcyonarian *Epizoanthus arenaceus*). Gili and Ballesteros (1991) described the species composition and abundance of the cnidarian populations in coralligenous concretions dominated by the gorgonian *Paramuricea clavata* from the Medes islands. Kružić (2002, 2007) described the cnidarian species composition in the Mljet National Park and Nature Park "Telašćica". In these papers species contributing the most to the total biomass of the taxocenosis were anthozoans *Leptopsammia pruvoti*, *Caryophyllia inornata*, *Caryophyllia smithii*, *Paramuricea clavata*, *Eunicella cavolini*, *Corallium rubrum*, *Alcyonium acaule* and *Parerythropodium coralloides*.

The assemblage of red coral in the Mediterranean is dominated by cnidarians *Corallium rubrum*, *Caryophyllia inornata, Caryophyllia smithii*, *Hoplangia durotrix*, *Phyllangia mouchezi*, and *Leptopsammia pruvoti*, sponges *Petrosia ficiformis* and *Aplysina cavernicola* and bryozoans *Celleporina caminata*, *Myriapora truncata*, *Smittina cervicornis* and *Reteporella beaniana.* Among the anthozoans, red coral is exploited commercially in almost all Mediterranean countries, and its stocks have strongly declined in most areas, particularly in shallow waters (Weinberg 1991).

Canals and Ballesteros (1997) estimated the carbonate production of the phytobenthos in the coralligenous and other communities from the continental shelf of the Balearic Islands. The coralligenous community thriving in relatively shallow waters (with *Mesophyllum alternans* and *Halimeda tuna* as dominant algae) was the one with the highest production (around 465 g $CaCO_3$ m^{-2} $year^{-1}$). Production of deep water coralligenous concretions dominated by *Lithophyllum cabiochae* was much lower (around 170 g $CaCO_3$ m^{-2} $year^{-1}$). However, estimates of the animal carbonate production in deep water (25–50 m depth) rocky bottoms from the Alboran Sea (southwestern Mediterranean), mainly dominated by big suspension feeders with calcareous skeletons (predominantly the coral *Dendrophyllia ramea*, the bryozoans *Pentapora fascialis*, *Smittina cervicornis* and *Myriapora truncata*, and polychaetes such as *Salmacina dysteri*, *Protula* sp. and other serpulids), are very high (around 660 g $CaCO_3$ m^{-2} $year^{-1}$) (Cebrian et al. 2000).

Maërl beds are also very diverse as coralligenous buildups. Coralline red algae (Corallinaceae) are usually the main constituents (most common are genus *Lithothamnion*, *Phymatolithon*, *Peyssonnelia* and *Litophyllum*) and live unattached. These species can form extensive beds, mostly in coarse clean sediments of gravels and clean sands or muddy mixed sediments, which occur either on the open coast, in tide-swept channels or in sheltered areas of marine inlets with weak current. Maërl beds form a complex

three-dimensional habitat and have been found to harbour greater diversity of life in comparison to surrounding habitats and have high productivity (Martin et al. 2005; Grall et al. 2006). The distribution of maërl is dependent on water movement, light and occurs in the photic zone, up to 120 m deep in the Mediterranean Sea. Maërl beds can act as nursery areas for the juvenile stages of commercial species of bivalves, fish, crabs and scallops.

Threats to Mediterranean Bioconstructors

Major Threats

Trawling and Dredging

Trawling is probably the most destructive impact currently affecting marine bioconstructors (like impact on coralligenous communities). As this fishing gear drags and rolls along and digs into the sea floor, the result is often habitat destruction. Trawling is also completely destructive in maërl beds, being the main cause of maërl disappearance in large Mediterranean areas. The action of trawling gear over coralligenous and maërl assemblages leads to the death of most engineering, dominant and builder species, completely changing the environmental conditions of the coralligenous microhabitats and from the maërl environment. Before the trawling the habitat was described as a clean maërl gravel with low silt content supporting abundant suspension feeding bivalves, but after the trawling the habitat is of muddy sand dominated by deposit feeders and omnivores. As most of these bioconstructional species are particularly long-lived, have low recruitment and complex demographic patterns, destruction of the coralligenous and maërl structure is critical as their recovery will probably take several decades or even centuries (Ballesteros 2006). Trawling close to coralligenous outcrops or maërl beds affects negatively to algal growth and suspension-feeding due to an increase in turbidity and sedimentation. Maërl has been dredged from both living beds and fossilised deposits for use as an agricultural soil conditioner as well as use in animal food additives and water filtration systems. Although quantities were initially small, by the 1970s a peak of around 600,000 tonnes were extracted per year in France (Briand 1991). Due to the very slow rate of growth, maërl is considered to be a non-renewable resource and, even if the proportion of living maërl in commercially collected material is low, extraction has major effects on the wide range of species present in both live and dead maërl deposits (Bárbara et al. 2003).

Dynamite Fishing

This illegal practice can be extremely destructive to the surrounding ecosystem, as the explosion often destroys the underlying habitat (such as coralligenous community). Dynamite fishing is set off under water to kill fish for easy collection or to attract fish from deeper bottom. The explosives used destroy the marine environment, leaving it devoid of life. Large blasted areas are very slow to recover because coralligenous communities have difficulty establishing on loose substrate. Dynamite fishing is one of the most pervasive fishing techniques and it is banned by most countries, but is, unfortunately, still frequent in Mediterranean.

Anchoring

Anchoring has a very severe impact in coralligenous concretions, as most of the engineering organisms are very fragile and are easily detached or broken by anchors and chains. Anchors can crush and destroy this valuable bottom through sediment disturbance and fragmentation. Coralligenous concretions of frequently visited sites by recreational fishing or diving activities are degraded by the destructive potential of anchors (Ballesteros 2006). While it is possible for sea-bottom habitats, such as coralligenous community, to recover from anchor damage, this is a very slow process that can usually take many decades. In areas of intense anchor damage, it is unlikely that this community will ever make a full recovery. In some areas in the Mediterranean, the anchoring is a huge problem even in protected areas, because of lack of monitoring control and management.

Invasive Species

There is a lack of knowledge on the effects that lessepsian species have on coralligenous and maërl communities in the Mediterranean. Currently, at least three algal species are threatening coralligenous and maërl communities in the Mediterranean: *Womersleyella setacea*, *Caulerpa racemosa v. cylindracea* and *Caulerpa taxifolia*. All of them are only invasive in relatively shallow water coralligenous outcrops and maërl beds (until 60 m), where irradiance levels are sufficient to permit their growth (Ballesteros 2006). However, they are especially dangerous, because they completely cover the basal stratum of encrusting corallines and increase sedimentation rates which lead to a total shut down of coralligenous growth or the survival of rhodolits. Probably the most dangerous alien species for the coralligenous community is the red alga *Womersleyella setacea*, which is currently distributed along most of the Mediterranean basin (Athanasiadis 1997). The species richness found in sites invaded by *W. setacea* is lower than that observed in noncolonised sites (Piazzi et al. 2002). The other two algae, *Caulerpa taxifolia* and *C. racemosa var. cylindracea* are species that can threaten the coralligenous community and in some areas they have totally invaded the coralligenous community, especially the second one (Meinesz and Hesse 1991; Piazzi et al. 2005). In the summer of 2004, *C. racemosa* var. *cylindracea* was found in the National Park Mljet in Veliko jezero between 8 and 14 m depth, affecting around 150 m of coastline and the

Fig. 25.4 Invasive alga *C. racemosa* var. *cylindracea* on the coral *Cladocora caespitosa*

marginal part of the coral bank of *Cladocora caespitosa* (Kružić et al. 2008) (Fig. 25.4). The alga was observed smothering live coral colonies, while the coral produced excessive mucus preceded by the complete retraction of the polyps, leaving the calyx rim deprived of tissue coverage.

Waste Water Discharges and Aquaculture

Waste waters profoundly affect the structure of coralligenous communities by inhibiting coralline algal growth, increasing bioerosion rates, decreasing species richness and densities of the largest individuals of the epifauna, eliminating some taxonomical groups and increasing the abundance of highly tolerant species (Hong 1980, 1982; Ballesteros 2006). Although there is no information available on the impact of eutrophication in Mediterranean maërl beds, the effects must be similar to those reported for coralligenous concretions. The number of coralligene species decreased with increased pollution, both in terms of number and density of individuals. It is also known that orthophosphate ions inhibit calcification (Simkiss 1964). Water turbidity seems to be the main factor causing degradation and homogenisation of the phytobenthos and some coral species. Because of algal blooms due high eutrophication, algae tend to grow very quickly under high nutrient availability and the result is a high concentration of dead organic matter which starts to decay. The decay process consumes dissolved oxygen in the water, resulting in hypoxic conditions. Without sufficient dissolved oxygen in the water, coralligene species may die off in large numbers. Marine mucilage on benthic species is also common in the area of eutrophication.

Although there are no studies on the impact of aquaculture facilities situated over or at the proximity of coralligenous outcrops, nor maërl beds, their effects should match those produced by waste water dumping. Coastal construction and increases in agricultural and sewage discharges may also have some impact if they increase sediment loads or result in the excessive growth of ephemeral species of macroalgae around maërl beds (Birkett et al. 1998).

Recreational Diving

The coralligenous community is one of the most popular sites for recreational diving in the Mediterranean due to its great variety of life and great visual appeal (Harmelin 1993). Uncontrolled or over-frequentation of divers in coralligenous communities has been described to produce an important effect over certain large or fragile suspension feeders inhabiting coralligenous communities (Sala et al. 1996; Garrabou et al. 1998; Coma et al. 2004; Linares et al. 2005; Ballesteros 2006). Impacts caused by recreational scuba activity vary widely among different divers with differing underwater behaviour. The proportion of damage varied significantly with the frequency of SCUBA diving and sometimes resulting in damage of bioconstructors like red algae and bryozoan and coral colonies.

Bioconstructors and Acidification

Anthropogenic carbon dioxide (CO_2) has already caused ocean pH to decrease by an average of 0.1 units since pre-industrial time (Raven et al. 2005). By 2100, it is projected to fall by 0.3–0.5 pH units (Orr et al. 2005). Short-term experiments have revealed that this degree of seawater acidification can alter calcification rates in certain planktonic and benthic organisms, although the effects recorded may be shock responses and the long-term ecological effects are unknown.

The level of acidification in the Mediterranean Sea is still poorly known, but certain characteristics of this semi-enclosed ocean makes it especially sensitive to increasing

atmospheric CO_2 (Calvo et al. 2011). The relationship between the rising concentration of atmospheric CO_2 and ocean acidification, together with the possible effect of the decline in seawater pH has been widely studied, especially over the last years. A first estimate indicates a pH decrease of up to 0.14 units since the pre-industrial era affecting the entire water column, especially in the western Mediterranean basin (Touratier and Goyet 2011). Only a few studies have tested the effects of ocean acidification in corals from the Mediterranean Sea. Faster growing colonies were the most affected by a decreased pH. Corals like *Balanophyllia europaea* and *Cladocora caespitosa* will also be detrimentally affected by the near future progressive ocean acidification. Rodolfo-Metalpa et al. (2010) combined short (1 month) and long (1 year) exposure of *C. caespitosa* to low pH (7.8 units) in experimental aquaria and found no detrimental effects in calcification rate of the colonies. In the second study, the transplantation of *C. caespitosa* corals to a gradient of naturally acidified areas close to CO_2 vents (pH level range between 8.1 and 7.5 units) showed evidences of dissolution (Rodolfo-Metalpa et al. 2011). The mussel *Mytilus galloprovincialis* and the limpet *Patella caerulea* showed similar trends in their ability to accrete shell under high CO_2 conditions. This suggested that the effects of acidification on these species may show up below a certain threshold of pH decrease. This study did not find evidence of dissolution on *Balanophyllia europaea* corals exposed to the same gradient of natural acidification. The authors also make the potentially important observation that the positive relationship between CO_2 and gross calcification for the coral *B. europaea* and the mussel *M. galloprovincialis* in early to mid-summer becomes negative following late summer warming of the Mediterranean Sea. They conclude that the combination of warming and acidification was simply too much for these calcifiers to overcome. Cigliano et al. (2010) reported that six main taxonomic groups (foraminiferans, nematodes, polychaetes, molluscs, crustaceans and chaetognaths) showed highly significant reductions in recruitment caused by acidified conditions near the vents (pH 7.08–7.79) at Ischia (Gulf of Naples, Tyrrhenian Sea), Italy. At the same site Rodolfo-Metalpa et al. (2010) reported that organic tissues enveloping the skeleton of the Mediterranean bryozoan *Myriapora truncata* play a protective role from the effects of ocean acidification on the species calcareous skeleton. Skeletons of live colonies in acidic pH site after 45 days of exposure were less corroded than those of dead bryozoan colonies.

Coralline algae are of significant importance, especially in the Mediterranean Sea where they are the major contributors to biogenic carbonate production. The study of Martin et al. (2008) shows a significant reduction in epiphytic coralline algal cover with increasing acidification of seawater due to natural CO_2 vents. Although a range of factors may be responsible for this observed shift in seagrass epiphytism, lowered pH and reduced calcite saturation levels are the most likely factors affecting coralline algal cover. Coralline algae were absent where the pH periodically fell below 7 and their calcimass was greatly affected where the pH ranged from 7.7 to 8.2. Jokiel et al. (2008) reported skeleton dissolution rather than growth for the species *Lithophyllum*, *Hydrolithon* and *Porolithon* sp. at a pH of approximately 7.9, relative to a normal pH of 8.2, while Kuffner et al. (2008) reported a drop in recruitment rate and per cent cover of 78 and 92 %, respectively, at a pH of 7.9.

The wide variety of experimental studies on the effects of ocean acidification on calcifying marine organisms like algae, corals and other carbonate dominated systems showed reduced calcification rates during increased acidification.

Bioconstructors and Mass Mortalities

Several episodes of mass mortalities have been detected in the northwestern Mediterranean (Rivoire 1991; Bavestrello et al. 1994; Cerrano et al. 2000; Garrabou 1999; Garrabou et al. 2001, 2009). In most cases, sessile marine organisms were victims of these large-scale mortality events that affected shallow water assemblages (5–40 m depth). The characteristic summer conditions of reduced resources, high water column stability and high temperatures (normally during July and August) lasted much longer than usual and this coincided with a mass mortality of benthic organisms, affecting also a coralligenous community, situated at a depth of <40 m. Red coral populations thriving above a depth of 30 m were also affected (Garrabou et al. 2001). This large-scale mortality, together with other small-scale mass mortalities recorded during the past decade in the Mediterranean, may be related to seawater temperature increase and global warming (Cerrano et al. 2000). Some suspension feeders might be able to withstand the normal duration of adverse summer conditions but not an anomalous prolongation of these conditions, resulting from an energy shortage of suspension feeders related to low food availability in summer (Coma et al. 2000; Coma and Ribes 2003). A mass mortality event of the red coral *Corallium rubrum* occurred in the NW Mediterranean region in summer 1999 (Garrabou et al. 2001). During late summer 1999, the NW Mediterranean area affected by the mass mortality event experienced high temperatures and hydrographic stability over a period of several weeks. This temperature anomaly could have caused physiological stress and triggered the development of pathogenic agents that otherwise would have remained non-virulent. There were no signs of mass mortality below 40 m depth in red coral populations. In late summer 2003, extensive mass mortality of at least 25 rocky benthic macroinvertebrate species (mainly gorgonians and sponges) was observed in the entire NW Mediterranean region (Garrabou et al. 2009).

Fig. 25.5 Bleached polyps of the coral *Cladocora caespitosa*

The heat wave of 2003 in Europe caused an anomalous warming of seawater, which reached the highest temperatures ever recorded in the studied regions, between 1 and 3 °C above the climatic values. It seems likely that the anomalous temperature played a key role in the observed mortality event. The western areas (Catalan coast and Balearic Islands) were the least affected, the central areas (Provence coast and Corsica-Sardinia) showed a moderate impact and the northernmost and eastern areas (Gulf of Genoa and Gulf of Naples) displayed the highest impact. The Adriatic Sea has been also affected by several severe mortality events of benthic invertebrate species during the last few decades (Kružić et al. 2012). The first unprecedented large-scale mass mortality event was recorded during summer 1997, affecting about 30 benthic species. Anomalous high-temperature conditions during summer 1997 were identified as the main triggering factor of these mortalities. Mortality events of the zooxanthellate corals *Cladocora caespitosa*, *Madracis pharensis* and *Balanophyllia europaea* and non zooxanthellate *Caryophyllia inornata* and *Leptopsammia pruvoti* were recorded in several sites in the Adriatic Sea during the summers of 1997, 1999, 2003, 2006 and 2009. At the end of the summer of 2003, about 30 % of the colonies of the coral *C. caespitosa* were damaged and more than 10 % of the damaged colonies were completely dead, all caused by bleaching events (Fig. 25.5). In most cases bleaching has been attributed to elevated temperature, but other instances involving high solar irradiance, and sometimes disease, have been also documented. These high temperature events involved coral colonies living in shallow water (6–25 m depth). Mortality was preceded by the complete retraction of the polyp, leaving the calyx rim deprived of tissue coverage. However, we cannot ascertain whether temperature had a direct effect on organisms or acted in synergy with a latent or waterborne agent (microbiological or chemical). Taking into account the global warming context in the Mediterranean Sea, monitoring programs of physical-chemical parameters and vulnerable coral populations should rapidly be set up.

Under the present climate warming trend, new mass mortality events may occur in the near future, possibly driving a major biodiversity crisis in the Mediterranean Sea, especially in Mediterranean bioconstructors.

Climate Change and Mediterranean Bioconstructors

How Climate Change Influences Bioconstructors

Current climate warming is superimposed over natural phenomena, some of which are cyclic. During the Last Glacial Maximum, ~23,000 to 19,000 years ago, the Mediterranean Sea surface temperature was 2 °C lower than today in the eastern basin, and up to 8 °C lower in the northwestern basin (Kuhlemann et al. 2008). The thermohaline circulation of the Mediterranean is determined by the flux of incoming Atlantic water by the Gibraltar Straits and by the sinking of waters formed at the three coldest areas of the sea: the Gulf of Lions, the northern Adriatic and the North Aegean Sea (Bianchi 2007). In the last few decades this general pattern has been disrupted in several ways. The first definite signs of changes in sea temperature came from Mediterranean deep waters. A 30-year time series (1959–1989) of deep-water temperatures acquired in the northwestern Mediterranean (NWM) demonstrated a general warming trend of ~0.12 °C (~0.004 °C per year), a possible result of human-induced global warming (Béthoux et al. 1990; Vargas-Yáñez et al. 2002). Some unexpected effects on thermohaline circulation have been documented from 1987 through the 1990s; these changes have been termed the Eastern Mediterranean Transient (EMT). Strong anomalies in temperature and rainfall are believed to

be involved in triggering the EMT, which has dramatically changed the hydrology of the deep eastern Mediterranean (Bianchi 2007; Roether et al. 2007). Temperature, salinity, stratification and circulation of water masses have been affected. A 30-year data set (1974–2005) from the Spanish Catalan coast first demonstrated the warming of the littoral zone at four different depths from the surface to 80 m and showed a clear trend at all depths, with an impressive warming of 1.4 °C at 20 m (Coma et al. 2009). Most of the introduced species in the Mediterranean originates from the Red Sea, as Lessepsian migrants (67 %), with an additional set of species (7 %) from other tropical areas (Bianchi 2007). In the colder Northwestern Mediterranean, tens of significant range expansions of species of warmwater affinity have been recorded. One of the examples is the warm stenotherm orange coral *Astroides calycularis*, very common in the eastern and southern shores and recently shifts its distribution northwestwards (Francour et al. 1994; Kružić 2002).

Climate change combines with Atlantic influx, lessepsian migration and the introduction of exotic species by humans to the establishment of tropical marine biota in the Mediterranean Sea (Bianchi 2007). Present-day warming ultimately favours the spread of warm-water species through direct and indirect effects, and especially by changing water circulation. Coral *Cladocora caespitosa* will certainly play the role of constructional coral in a more and more 'tropical' Mediterranean Sea (Bianchi 2007). In coincidence with positive anomalies of sea surface temperature recorded in these last few summers, this coral species, together with *Balanophyllia europaea* and *Madracis pharensis*, underwent mass-mortality events, recalling those observed in the tropics (Rodolfo-Metalpa et al. 2000; Garrabou et al. 2001).

If mass mortalities are indeed related to the global warming trend, such events might occur again and become more frequent, which would cause profound changes in the specific composition and structure of marine communities (Ballesteros 2006). It is not known whether all parts of the Mediterranean will be equally affected by global change. Different climatic conditions are involved in the Mediterranean basin, so answers might come from current efforts to ensure that several eastern and southern Mediterranean stations begin continuous records of temperature and of some indicator species (sessile invertebrates like corals and bryozoans). This will help us to understand the climatic changes in the Mediterranean and how will species cope with ongoing changes.

Temperature Anomalies in the Mediterranean

Anomalous high water temperatures seem to trigger large scale mortalities of several suspension feeders growing in coralligenous assemblages (Cerrano et al. 2000; Pérez et al. 2000). Most of the organisms living in coralligenous communities are able to support the normal seasonal temperature range characteristic of Mediterranean waters which are in the range of 10–20 °C. Pascual and Flos (1984) found temperatures ranging between 12 and 20 °C at the shallowest limit of the coralligenous communities of the Medes Islands (20 m depth), although temperatures ranged from 12 to 16 °C close to their deepest limit (60 m depth). Ballesteros (1992) reported more or less the same temperatures for the coralligenous assemblages developing at depths of 20 and 40 m at Tossa de Mar between the end of November and the end of June (13–16 °C), but differences of up to 9 °C in summer, when the thermocline is situated at a depth of around 35 m; however, peak temperatures of 22 °C were detected at the end of August at a depth of 40 m. In the Balearic Islands, where coralligenous communities are restricted to waters >40 m deep, water temperature ranges from 14.5 to 17 °C for most of the year, although occasional peaks of 22 °C are detected at the end of October, when the thermocline is at its deepest (Ballesteros and Zabala 1993). In the Adriatic Sea water temperature of the coralligenous communities In National Parks "Mljet" (southern Adriatic) and "Kornati" (central Adriatic) peak temperatures of 24 °C were detected at the in August and September at a depth of 40 m (Kružić unpublished data). Some organisms living in coralligenous assemblages from deep waters seem to be highly stenothermal, as they are never found in shallow waters. Recent large-scale mortality events of benthic suspension feeders thriving in coralligenous communities have been attributed to unusually long-lasting periods of high temperatures during summer (like in the Adriatic Sea).

Sea temperature anomalies have also an impact on calcification in bioconstructors. The results of Bessat and Buiges (2001) and Crabbe (2008) indicated that a 1 °C rise in temperature would lead to an increase in the density rate of about 10.5 % and an increase in the calcification rate of about 4.5 %. The growth rates of the coral *Cladocora caespitosa* were studied in the Ligurian and Adriatic Sea (Peirano et al. 1999, 2004, 2005; Morri et al. 2001; Peirano and Kružic 2004; Kružić and Benković 2008) and near the Columbretes Islands (NW Mediterranean, Spain) (Kersting and Linares 2012). The results showed that the growth rate seemed to correlate with climate fluctuations. Coral calcification rates and extension rates have been highly correlated with sea surface temperatures (SSTs), and to a lesser extent with incoming solar radiation (Lough and Barnes 2000). Although there are numerous studies of the relationships between environmental parameters and coral growth in the tropics, such studies are scarce for temperate zones. Unlike most studies on other tropical and temperate corals, in which calcification was positively correlated with solar radiation and SST, studies in the Mediterranean showed that calcification was not correlated with solar radiation, whereas it was negatively correlated with SST (Goffredo et al. 2009). Kushmaro et al. (1998)

reported that high temperatures (about 29 °C) caused rapid bleaching and dying of the coral *Oculina patagonica* from the Mediterranean Sea as a result of a bacterial infection. It is recognized that heat stress triggers diseases in marine waters, and the frequency of this event clearly increased over the last two decades. Mortality of the coral *C. caespitosa* caused by elevated water temperatures has also been described by Rodolfo-Metalpa et al. (2000, 2005, 2006) in the Ligurian Sea, as well as by Cerrano et al. (2000), Ferrier-Pagès et al. (2009), and Garrabou et al. (2001, 2009) in other sessile marine invertebrates. Laboratory observations on the calcification rates of the coral *C. caespitosa* and *O. patagonica* indicate that prolonged periods of high temperatures lead to a decrease in calcification (Rodolfo-Metalpa et al. 2006). Recent extreme temperature events in the Mediterranean Sea are likely to have disturbed the normal functioning of biological systems. Exposure to anomalous high temperatures can act directly to cause metabolic dysfunctions (Coma and Ribes 2003; Coma et al. 2009) or indirectly by favoring the development of pathogens (Bally and Garrabou 2007).

Future of Bioconstructors in the Mediterranean

Projections available for the Mediterranean basin region for the twenty-first century indicate warmer and drier conditions with a dramatic increase in the frequency and persistence of extreme events such as heat waves (Stott et al. 2004; Diffenbaugh et al. 2007). In the Black Sea and Mediterranean Sea there is no danger of surface waters becoming corrosive to calcium carbonate before 2100, but they will suffer sharp reductions in carbonate ion concentrations (Mediterranean Sea – 37 %; Black Sea – 45 %) (McNeil and Matear 2008; Steinacher et al. 2009). These rapid chemical changes are an added pressure on marine bioconstructors and ecosystems of the Mediterranean that are already heavily suffering from other anthropogenic influences. Consequences of these events could severely expose populations of affected species to local ecological extinction processes, threatening the conservation of the rich Mediterranean biodiversity (Bianchi and Morri 2000; Ballesteros 2006; Bianchi 2007). This climate change is the latest form of human disturbance affecting the Mediterranean coastal communities at the regional scale through mortality outbreaks and shifts in species distributions (Francour et al. 1994; Bianchi and Morri 2000). The expansion and intensification of climate change effects together with the effects of other strong disturbances (pollution, mechanical habitat destruction, invasive species, and overfishing) may act together, driving the Mediterranean to a major biodiversity crisis during the twenty-first century (Bianchi and Morri 2000; Sala 2004).

Although most experimental studies on ocean acidification to date have focussed on tropical assemblages, recent work has shown that effects of ocean acidification on temperate marine systems may be equally complex and deleterious (Hall-Spencer et al. 2008; Martin and Gattuso 2009; Russell et al. 2009). Atmospheric CO_2 partial pressure (pCO_2) is expected to increase to 700 µatm or more by the end of the present century. Anthropogenic CO_2 is absorbed by the oceans, leading to decreases in pH and the $CaCO_3$ saturation state (Ω) of the seawater. Elevated pCO_2 was shown to drastically decrease calcification rates in tropical zooxanthellate corals. Therefore, the conventional belief that calcification rates will be affected by ocean acidification may not be widespread in temperate corals. Rodolfo-Metalpa et al. (2010) showed, using the Mediterranean zooxanthellate coral *Cladocora caespitosa*, that an increase in pCO_2, in the range predicted for 2100, does not reduce its calcification rate. Seasonal change in temperature is the predominant factor controlling photosynthesis, respiration, calcification and symbiont density. An increase in pCO_2, alone or in combination with elevated temperature, had no significant effect on photosynthesis, photosynthetic efficiency and calcification. The lack of sensitivity *C. caespitosa* to elevated pCO_2 might be due to its slow growth rates, which seem to be more dependent on temperature than on the saturation state of calcium carbonate in the range projected for the end of the century.

Global ocean models predict surface pH reductions of 0.3–0.5 units by the year 2100 due to the uptake of anthropogenic CO_2 (Caldeira and Wickett 2005). This is likely to have strong negative impacts on coralline algae (Hall-Spencer et al. 2008). Ocean warming could also have particularly severe effects on some maërl species due to their fragmented ranges and poor dispersal but only limited knowledge of temperature tolerances and optima are available for some species of maërl (Blake and Maggs 2003).

In some areas of the Mediterranean, there are recurrent downwellings (>40 m) during summer, which carries increased temperature further down in the water column, resulting in warm conditions over longer periods. This phenomenon could be enhanced with the influence of Mistral (NWN) and Bora (NEN) winds. The lower frequency and shorter duration of these winds prevent the upwelling of deep, cold waters and the subsequent breakage of the thermocline, thus allowing the temperature to increase. Continued sea warming is likely to affect the successful recruitment, growth and productivity of prominent coastal organisms like marine bioconstructors.

There is currently no evidence of changes attributable to non-temperature related climate impacts, potentially due to a lack of long-term observational data, experimental evidence suggests that ocean acidification will result in negative effects on calcifying algae and animals (Wernberg et al. 2011). More importantly, recent experiments suggest the combined effects of climate change and non-climate stressors (overharvesting, reduced water quality) will lower the resilience of temperate marine communities to

perturbations (storms, diseases, and invasive species), many of which are also predicted to increase in frequency and severity.

Since most of the predictions about future of the bioconstructors were made upon experimental laboratory work, the future of the Mediterranean climatic change could show us different picture than what scientists predicted. Coral *Cladocora caespitosa* have huge range of temperature tolerance (from 6 °C in winter period to 29 °C in summer period) without bleaching episodes. Bleaching of *C. caespitosa* took place with prolonged periods of low or high sea temperatures or when these extreme temperatures appear suddenly causing stress phenomena. Corals or other constructional organisms are not getting more abundant. On the contrary, the native constructional coral *Cladocora caespitosa* and other large invertebrate or coraline bioconstructors that 'shape' the submarine seascape of coastal Mediterranean ecosystems are perhaps going to face more frequent mass mortality events (Bianchi 2007).

The novel environmental conditions generated by climate change (increases in temperature and CO_2 concentrations) are likely to drive greater change in localities that have lower resilience (e.g. nutrient pollution on oligotrophic coasts) to combinations of global and local stressors (Wernberg et al. 2011). Future patterns of species diversity and their individual functions will be a product of the temporal modification of spatial opportunities and constraints for colonisation and persistence.

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